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Superconductivity versus bound-state formation in a two-band superconductor with small Fermi energy: Applications to Fe pnictides/chalcogenides and doped SrTiO3

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Abstract

© 2016 American Physical Society.We analyze the interplay between superconductivity and the formation of bound pairs of fermions (BCS-BEC crossover) in a 2D model of interacting fermions with small Fermi energy EF and weak attractive interaction, which extends to energies well above EF. The 2D case is special because a two-particle bound state forms at arbitrary weak interaction, and already at weak coupling, one has to distinguish between the bound-state formation and superconductivity. We briefly review the situation in the one-band model and then consider two different two-band models: one with one hole band and one electron band and another with two hole or two electron bands. In each case, we obtain the bound-state energy 2E0 for two fermions in a vacuum and solve the set of coupled equations for the pairing gaps and the chemical potentials to obtain the onset temperature of the pairing Tins and the quasiparticle dispersion at T=0. We then compute the superfluid stiffness ρs(T=0) and obtain the actual Tc. For definiteness, we set EF in one band to be near zero and consider different ratios of E0 and EF in the other band. We show that at EF-E0, the behavior of both two-band models is BCS-like in the sense that Tc≈Tins EF and Δ~Tc. At EF-E0, the two models behave differently: in the model with two hole/two electron bands, Tins~E0/lnE0EF, Δ~(E0EF)1/2, and Tc~EF, like in the one-band model. In between Tins and Tc, the system displays a preformed pair behavior. In the model with one hole and one electron bands, Tc remains of order Tins, and both remain finite at EF=0 and of the order of E0. The preformed pair behavior still does exist in this model because Tc is numerically smaller than Tins. For both models, we reexpress Tins in terms of the fully renormalized two-particle scattering amplitude by extending to the two-band case (the method pioneered by Gorkov and Melik-Barkhudarov back in 1961). We apply our results for the model with a hole and an electron band to Fe pnictides and Fe chalcogenides in which a superconducting gap has been detected on the bands that do not cross the Fermi level, and to FeSe, in which the superconducting gap is comparable to the Fermi energy. We apply the results for the model with two electron bands to Nb-doped SrTiO3 and argue that our theory explains the rapid increase of Tc when both bands start crossing the Fermi level.

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